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In re patent application of

Peter GESKES et al.

Corres. to PCT/EP2004/010516

For: FLOW CHANNEL FOR A HEAT EXCHANGER, AND HEAT EXCHANGER COMPRISING SUCH FLOW CHANNELS

TRANSLATOR'S DECLARATION

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I, the below-named translator, certify that I am familiar with both the German and the English language, that I have prepared the attached English translation of International Application No. PCT/EP2004/010516, and that the English translation is a true, faithful and exact translation of the corresponding German language paper.

I further declare that all statements made in this declaration of my own knowledge are true and that all statements made on information and belief are believed to be true; and further, that these statements were made with the knowledge that willful, false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful, false statements may jeopardize the validity of legal decisions of any nature based on them.

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Flow passage for a heat exchanger, and heat exchanger having flow passages of this type

The invention relates to a flow passage, through which a medium can flow in a direction of flow, of a heat exchanger in accordance with the preamble of patent claim 1. The invention also relates to a heat exchanger having flow passages in accordance with the preamble of patent claim 40.

A first medium, for example an exhaust gas or a liquid coolant, flows through flow passages for heat exchangers, and these flow passages delimit this first medium from a second medium, to which the heat of the first medium is to be transferred. Flow passages of this type may be tubes with a round cross section, rectangular tubes, flat tubes or also pairs of disks, in which case two plates or disks are connected at the edge sides. The media which exchange heat with one another are generally different; by way of example, a hot exhaust gas laden with particulates flows within the tubes, and a liquid coolant flows around the exhaust-gas tubes on the .outer side, leading to different heat transfer conditions on the inner and outer sides of the tubes. It has therefore been proposed, in particular for exhaust-gas tubes, that turbulence generators arranged in a V-shape and in diffuser fashion be arranged on their inner side, these turbulence generators being responsible for swirling up the flow and improving the heat transfer on the exhaust-gas side while at the same time preventing deposition of particulates. Solutions of this type for exhaust-gas heat exchangers are known from the

following documents in the name of the Applicant: EP-A 677 715, DE-A 195 40 683, DE-A 196 54 367 and DE-A 196 54 368. These known exhaust-gas heat exchangers have rectangular tubes made from stainless steel which are assembled from two half-shells welded together, into which the turbulence generators, known as winglets, are formed or stamped, arranged one behind the other. The winglet pairs of the two half-shells are offset with respect to one another either in the longitudinal direction of the tubes, i.e. in the direction of flow (DE 196 54 367, DE 196 54 368) or are arranged opposite one another (DE 195 40 683).

DE-A 101 27 084 in the name of the Applicant has proposed a heat exchanger, in particular a coolant/air cooler with flat tubes and corrugated fins, in which the flat sides of the flat tubes have a structure comprising structure elements. The structure elements are elongate in form, are arranged in a V shape in rows transversely with respect to the direction of flow of the coolant and/or transversely with respect to the longitudinal axis of the tubes and function as swirl generators in order to increase the heat transfer on the coolant side. The swirl generators are stamped into the two opposite tube walls and project inwardly into the coolant flow. The rows of swirl generators on a flat tube side are offset in the direction of flow with respect to the rows on the other flat tube side. It is therefore also possible for the inwardly projecting height of the swirl generators to be greater than half the clear width of the cross section of the flat tube.

EP-A 1 061 319 has disclosed a flat tube for a motor vehicle radiator which on its flat sides has a structure comprising individual elongate structure elements arranged in rows. Rows with differently oriented structure elements are arranged in the direction of flow, so that the flow in the interior of

the flat tube is diverted approximately in a zigzag shape. In particular, however, the rows comprising structure elements on one flat tube side are arranged offset in the direction of flow with respect to the rows on the opposite flat tube side. Therefore, a smooth region of the flat tube inner wall in each case lies opposite a row of structure elements. The flow within the coolant tube is therefore alternately but not simultaneously influenced by the structure elements on one flat tube side and the other flat tube side. This is intended, inter alia, to prevent the tubes from becoming blocked. There is also potential in this respect with regard to the heat transfer capacity.

It is an object of the present invention to improve a flow passage and a heat exchanger of the type described in the introduction with regard to its heat transfer capacity, in particular to increase the formation of turbulence and swirl, while the pressure loss should only rise by an acceptable degree.

This object is achieved by the features of patent claim 1. According to the invention, it is provided that the structure elements arranged in particular in rows on one side and the other side of the flow passage are positioned substantially opposite one another, i.e. are in each case arranged at approximately the same level as seen in the direction of flow. The structure elements or rows lying opposite one another may also be offset with respect to one another in the direction of flow, although only to such an extent that an overlap still exists. Therefore, structure elements projecting into the flow passage from one heat exchanger surface and the other heat exchanger surface intervene simultaneously in the flow and swirl up the flow, which leads to an improvement in the heat transfer on the inner side of the flow passage. Furthermore - for example in the case of an exhaust-gas flow - under

certain circumstances deposition of particulates is prevented. The pressure loss is kept within acceptable limits. The flow within the flow passage is therefore disturbed from both sides simultaneously, i.e. both boundary layers are detached simultaneously, which leads to particularly extensive swirling. The structure elements or rows of structure elements lying opposite one another may likewise be located on the outer side of the flow passage - in the case of an exhaust-gas cooler on the coolant side. Advantageous configurations of the invention will emerge from the subclaims.

In the context of the present invention, a row comprising structure elements is formed by one or more structure elements which are arranged substantially next to one another in the direction of flow P. In particular, therefore, a row may also be formed by a single structure element with, for example, no further structure elements arranged next to it.

Advantageous configurations of the invention provide for different embodiments of the structure elements, which may be rectilinear or curved in form, i.e. may have a constant or variable flow-off angle with respect to the direction of flow. Changing the flow-off angle from a relatively large flow-on angle to the flow-off angle results in a "gentle" diversion of the flow and therefore a somewhat reduced pressure loss. According to a further advantageous configuration of the invention, the structure elements within a row may be arranged offset, i.e. the structure elements, although arranged in a row running transversely with respect to the direction of flow, are arranged staggered in the direction of flow. This likewise has the advantage of a lower pressure loss. Furthermore, opposite rows, i.e. on one flat tube side or the other, may be arranged offset with respect to one another in the direction of flow, in which case, however, an overlap is always

retained between the two rows. This offset in the direction of flow also results in a lower pressure loss. If the structures lying opposite one another touch one another and if they are joined to one another by welding or soldering, it is possible to increase the strength. According to another variant, the structure elements are not arranged at equal distances within a row, but rather these rows have voids, which in each case have structure elements lying opposite them on the opposite side, thereby "filling up" these voids, as seen in plan view. This likewise has the advantage of a lower pressure loss.

It is also possible for studs and/or webs to be stamped inward or outward (as seen in the direction of flow P) between or next to the structure elements and/or between or within the "structure rows" (rows comprising structure elements), in order thereby to achieve a "supporting" action and therefore an increase in strength. The swirl-generating structures may likewise be completely or partially responsible for this function.

According to an advantageous embodiment, the heat exchange surfaces which lie substantially opposite one another, and in particular the structure elements arranged thereon, are curved. The advantages according to the invention are achieved in particular with tubes having a circular or oval cross section.

According to an advantageous embodiment, the heat exchange surfaces which lie substantially opposite one another are heat-engineering primary surfaces. According to a variant, the heat exchange surfaces, by contrast, are heat-engineering secondary surfaces, which are formed in particular by fins, webs or the like which are preferably clamped, welded or soldered to the flow passage.

According to an advantageous embodiment, the height h of the structure elements is in the range from 2 mm to 10 mm, in particular in the range from 3 mm to 4 mm, and is preferably around 3.7 mm.

According to an advantageous embodiment, the flow passage is rectangular and has a width b which is in particular in the range from 5 mm to 120 mm, preferably in the range from 10 mm to 50 mm.

According to an advantageous embodiment, a hydraulic diameter of the flow passage is in the range from 3 mm to 26 mm, in particular in the range from 3 mm to 10 mm.

According to an advantageous embodiment, at least one, in particular each row of structure elements, comprises in each case a plurality of structure elements.

The object of the invention is also achieved by the features of patent claim 40. According to the invention, the abovementioned flow passages are provided as flat, round, oval or rectangular tubes of a heat exchanger, advantageously an exhaust-gas heat exchanger. The arrangement of the structure elements according to the invention, i.e. the way they are advantageously stamped into the tube inner walls, improves the performance of the heat exchanger. The structure elements arranged in rows are particularly advantageous for exhaust-gas heat exchangers, since in this case deposition of particulates in the interior of the flat tubes is also avoided. A coolant which is taken from the coolant circuit of the internal combustion engine discharging the exhaust gases flows around the outer side of the exhaust-gas tubes. It is also possible for the structures to be stamped into plates or disks in order for heat exchangers to be

produced therefrom.

Exemplary embodiments of the invention are illustrated in the drawings and described in more detail in the text which follows. In the drawings:

Fig. 1 shows a flow passage according to the prior art,

Figs. 2a,b,c show a cross section through flow passages,

Fig. 3 shows a flat tube with a structure according to the invention,

Fig. 4 shows a half-shell of the flat tube from Fig. 3,

Figs. 5a,b,c,d show various structure elements,

Figs. 6a,b,c,d,e,f,g,h show structures according to the invention on flow passages,

Figs. 7a,b show further structures according to the invention,

Fig. 8 shows a further structure according to the invention,

Figs. 9a,b,c,d show mirror-image structure elements,

Figs. 10a,b,c,d show parallel-offset structure elements,

Figs. 11a,b,c,d show rows of structure elements with modifications, and

Figs. 12a,b, show further structure elements.

Fig. 1 shows a simplified illustration of a flow passage 1 which is formed as a rectangular tube and has a rectangular entry cross section 2, two opposite flat sides F1, F2 and two opposite narrow sides S1, S2. A flow medium, for example an exhaust gas, flows through the passage 1 in the direction indicated by arrow P. Swirl generators 3a, 3b, 4a, 4b oriented in V shapes are arranged on the lower flat side F2 and, by generating swirl, effect increased turbulence of the flow and at the same time - in the case of an exhaust-gas flow - prevent deposition of particulates. This illustration corresponds to the prior art mentioned in the introduction. Accordingly, the swirl generators 3a, 3b and 4a, 4b, which are in each case arranged in pairs, set up in a V shape and widen in diffuser fashion in the direction of flow, are also referred to as what are known as winglets.

Fig. 2a shows the cross section through a flow passage 1 which is formed as a flat tube and in which winglet pairs 5a, 5b and 6a, 6b are arranged on both the upper flat side F1 and the lower flat side F2. The passage cross section has a passage height H and a passage width b. The winglets 5a, 5b, 6a, 6b have a height h projecting into the passage cross section. This arrangement of winglets likewise corresponds to the prior art cited in the introduction. The designations F1, F2 also apply to the exemplary embodiments according to the invention described below.

Fig. 2b shows the cross section through a flow passage 1' which is formed as a round tube and in which structure elements 13' and 13 are arranged both on the upper flat side F1 and on the lower flat side F2, respectively. The passage cross section has a passage height H.

Fig. 2c shows a cross section through a flow passage 1 which is formed as a flat tube and in which the heat exchange surfaces F1, F2 represent heat-engineering secondary surfaces, since they do not directly transfer heat from one medium to the other. The heat exchange surfaces have structure elements 13, 13'.

Fig. 3 shows a flow passage according to the invention, which is formed as a flat tube 7, part of which is illustrated in plan view. The flat tube 7 has a longitudinal axis 7a, a width b and two rows 8, 9 of structure elements or winglets 10, 11 which are arranged in a V shape and are in each case stamped both into the upper side F1 and the underside F2 of the flat tube 7, specifically in the same pattern, so that in each case the upper winglet row covers the row below it. In each case eight winglets, distributed uniformly over the entire width b, are arranged in a row; however, it is also possible for there to be six or seven winglets for the same width. In the case of narrow tubes, disks or plates, the number of winglets may also be fewer than six, and in the case of wider tubes or disks/plates, there may also be more than eight winglets. The two rows 8, 9 are at a distance s, which is measured from center to center and amounts to approximately two to six times the length of the winglets, from one another. Between the individual rows, there is therefore in each case a smooth region into which, for example, supporting structures have been stamped. The rows of winglets extend over the entire length of the flat tube 7, in each case at the distance s, specifically on both sides of the flat tube 7.

Fig. 4 shows a lower half-shell 7b of the flat tube 7 as seen in the direction of the longitudinal axis 7a of the flat tube 7. The half-shell 7b has a base F2 and two lateral limbs 7c, 7d, winglets 11' being arranged

on the base or underside F2, i.e. stamped into the tube wall. The upper half-shell is not illustrated; it is formed in mirror-image fashion and is longitudinally welded to the lower half-shell 7b at the lateral limbs 7c, 7d. The winglets 11' have a height h by which they project into the clear cross-sectional region of the flat tube 7. The tube may also be produced from a metal sheet which is deformed and welded on one side.

In a preferred exemplary embodiment, the width b of the flat tube is 40 mm or 20 mm, the total height of the flat tube is approximately 4.5 mm and the height h of the winglets is approximately 1.3 mm. As a result of the winglets projecting into the passage cross section from both sides, in each case to a height of 1.3 mm, given a clear passage height of 4.0 mm, a clear cross-sectional height of 1.4 mm remains for a core flow. The distance s between the rows is approx. 20 mm.

The flat tube 7 is preferably used for exhaust-gas heat exchangers (not shown) which are known per se, i.e. an exhaust gas from an internal combustion engine of a motor vehicle flows through it on its inner side, while coolant from a coolant circuit of the internal combustion engine cools it on its outer side. The outer side of the flat tubes 7 - as known from the prior art - may be smooth and held at a distance from adjacent tubes for example by stamped-in studs. However, it is also possible for fins to be provided on the outer side of the flat tubes 7 in order to improve the heat transfer on the coolant side.

Figures 5a, 5b, 5c and 5d show individual structure elements which are provided for a structure according to the invention on the flow passages.

Fig. 5a shows an elongate structure element 13 having a longitudinal axis 13a which forms an angle α, the

flow-off angle, with a reference line q. The direction of flow is the same for all the illustrations in Figures 5a to 5d and is indicated by an arrow P. The reference line q runs perpendicular to the direction of flow P. The structure element 13 has a length L and a width B. The latter may be constant or variable, i.e. may increase in direction P.

Fig. 5b shows an elongate but angled structure element 14 with two longitudinal axes 14a, 14b which are at an inclination with respect to one another and respectively include an angle α and β with the reference line q. β is referred to here as the flow-on angle and α as the flow-off angle. The flow indicated by arrow P is therefore diverted in two stages, i.e. initially only slightly and then to a greater extent. This results in a lower pressure loss compared to a structure element as shown in Fig. 5a with the same flow-off angle α. The length of the structure element 14 along the longitudinal axes 14a, 14b is denoted by L.

Fig. 5c shows an arcuate structure element 15 having a curved longitudinal axis 15a which corresponds to an arc of radius R. The upstream angle is referred to as the flow-on angle β and the downstream angle as the flow-off angle α. In this case too, the flow is initially diverted gently through the angle $(90°-\beta)$ and then to a greater extent by the angle $(90°-\alpha)$. This continuously increasing diversion of the flow likewise results in a lower pressure loss compared to the structure element 13 shown in Fig. 5a. The length of the structure element 15 along the longitudinal axis 15a is denoted by L.

Fig. 5d shows a further embodiment of a structure element 16, which is approximately Z-shaped in form and also has a longitudinal axis 16a running in a Z shape.

The longitudinal axis 16a connects two arc sections of different curvature, but with the same radius R1 = R2. The flow-on angle is denoted here by β, the flow-off angle by α, corresponding to a flow diversion of $(90°-\alpha)$, which takes place in the central region of the structure element 16. The flow onto and off this structure element takes place practically in direction of flow P. This results in the flow being diverted with particularly low pressure losses. The length of the structure element along the longitudinal axis 16a is denoted by L.

Figs. 6a, 6b, 6c, 6d, 6e, 6f, 6g, 6h show arrangement patterns of the structure elements 13 in accordance with Fig. 5a, specifically in rows on part of a flow passage. In exemplary embodiments which are not illustrated, only single structure elements lie opposite one another.

Fig. 6a shows the elongate structure elements 13 in each case arranged in two rows 17, 18 which are at a distance s in the direction of flow P. The structure elements 13 illustrated by solid lines are stamped into the upper side F1 of the flow passage. Structure elements 13' illustrated by dashed lines and likewise arranged in rows 19, 20 have been formed in the lower heat exchanger surface or side F2 of the flow passage. The rows are illustrated by dashed demarcating lines. The structure elements 13' on the lower surface F2 are oriented in the opposite direction to the structure elements 13 on the upper surface F1, i.e. they have an opposite flow-off angle α (cf. Fig. 5a). Furthermore, the rows 19, 20 are offset in direction of flow P with respect to the rows 17, 18, specifically by the amount f. The structure elements 13 and 13' and the associated rows 17, 18, 19, 20 each have a depth T, i.e. an extent in the direction of flow P. The offset f is less than the depth T, so that an overlap Ü which results from

the difference between T and f remains between the rows 18, 20 and 17, 19. An overlap Ü of 100%, in the case of rows with the same depth T, means that the offset is equal to 0 (f = 0). In the case of rows with different depths T1 and T2, i.e. for example T1 < T2, an overlap of 100% means that the overlap Ü is equal to the smaller depth T1 (Ü = T1). An offset between the rows 17, 19 and 18, 20 lying opposite one another advantageously results in a lower pressure loss than in the case of rows without an offset.

Fig. 6b shows a different pattern of structure elements 13 arranged in rows, specifically in a row 21 and a row 22 with different flow-off angles α (not shown). The structure elements 13 shown by solid lines have been stamped into the upper side F1 of the flow passage. Structure elements 13' illustrated by dashed lines at the same level, in the direction of flow P, with an opposite orientation are arranged on the lower surface F2 of the flow passage, with the result that an upper structure element 13 and an opposite lower structure element 13', when seen in plan view, in each case appear in the form of a cross. The upper row having structure elements 13 is therefore not offset with respect to the lower row comprising structure elements 13'; the overlap Ü is 100%.

Fig. 6c to Fig. 6h show further arrangement patterns for the structure elements 13, 13' on the upper side F1 (illustrated by solid lines) and the underside F2 (illustrated by dashed lines) of the flow passage.

Furthermore, Fig. 6h shows supporting elements 13'' on the outer side of the flow passages, which supporting elements in this exemplary embodiment are arranged adjacent to the structure elements 13, 13' and in particular within the rows formed by the structure elements 13, 13'. It is preferable for the supporting

elements to be stamped into the wall of the flow passage. For desired supporting of the respective flow passage, the supporting elements 13'' advantageously have a height which corresponds to the desired distance between two flow passages or between the respective flow passage and a housing wall of a heat exchanger.

Figures 7a and 7b show further variants for the arrangement of the structure elements 13 in rows.

Fig. 7a shows part of a flow passage with two rows 23, 24 of structure elements 13 arranged in a V shape on the upper side F1. The structure elements 13 are not arranged at constant distances next to one another, but rather have voids 25, 26, 27 which, however, are filled on the underside F2 by structure elements 13', so that when seen from above the impression is of a continuous, uniform arrangement of structure elements 13 and 13'. This arrangement of rows 23, 24 with "voids" and of the corresponding rows on the underside results in a lower pressure loss for the flow in direction P, because the structure elements - as seen in the width direction - only intervene in the flow alternately from above and below.

Fig. 7b shows a similar arrangement of structure elements 13 oriented parallel to one another with voids between them on the upper side F1 in rows 28, 29. The voids between the structure elements 13 are once again filled by structure elements 13' on the underside F2, the structure elements 13 on the upper side F1 and the structure elements 13' on the underside F2 complementing one another to form a zigzag arrangement when seen from above. This arrangement likewise involves relatively low pressure losses.

Fig. 8 shows another embodiment for the arrangement of structure elements 13 and 13' in two rows 30, 31 on the

upper side F1. The structure elements 13 of the row 30 and the structure elements 13' of the opposite row (on the underside F2) are arranged parallel to and at the same distance from one another. The same applies analogously to the second row 31, except that the flow-off angle is oppositely directed, resulting in a diversion of the flow as seen in the direction of flow P.

Figures 6a, 6b, 7a, 7b and 8 in each case illustrated structures having the structure elements 13 as shown in Fig. 5a. The structure elements 13 may equally be replaced by structure elements 14 (in Fig. 5b), 15 (Fig. 5c) or 16 (Fig. 5d). It would equally be possible to use different structure elements, for example 13 and 14, within a single row.

Figs. 9a, 9b, 9c, 9d show variants of the structure elements 13, 14, 15, 16 which are in a mirror-image arrangement: the result, therefore, is what are known as winglet pairs 32, 33, 34, 35, with a minimum distance a in each case being provided between two structure elements. The direction of flow generally takes place in the direction indicated by arrow P, with the flow onto the winglet pairs customarily taking place at the narrowest point a. This results in the different winglet pairs 32 to 35 having decreasing pressure losses in that order. These winglet pairs may be arranged in rows next to one another, for example as illustrated in Figures 6 to 8.

Figures 10a, 10b, 10c, 10d show further variations of the structure elements 13, 14, 15, 16 brought about by a parallel shift. This results in double elements 36, 37, 38, 39 in each case having the same distances a at the flow-on and flow-off sides, which, for example, can be integrated in the structures shown in Figs. 6 to 8.

It is in this context important that the structure elements of a row at the top and/or the bottom do not necessarily have to have the same geometric shape or dimensions, as shown by way of example on the basis of four structure elements in Fig. 11a. Rather, as shown in Fig. 11b, it is possible for the structure elements to be arranged with an offset f in the direction of flow P.

In Fig. 11c, the flow-off angles of the structure elements 13 vary, and in Fig. 11d the lengths L1, L2 of the structure elements 13 vary. A combination (not illustrated) of the variants illustrated in Figs. 11b, 11c, 11d is likewise possible. It is also possible for these variations to occur in the upper and/or lower surface F1 or F2, respectively.

Fig. 12a shows a further structure element 43, which is formed as an angle with two straight limbs 43a, 43b which are connected by an arc 43c at their apex. In this respect, this structure element 43 represents a modification of the winglet pair 32 illustrated in Fig. 9a. The medium preferably flows on in the direction of the apex 43c, as indicated by arrow P.

Fig. 12b shows a further modification of the structure element pair 34 as shown in Fig. 9c, namely a structure element 44 with two curved limbs 44a, 44b which are connected by an arc 44c at the apex. The structure element 44, onto which medium likewise flows in the direction of the apex 44c as indicated by arrow P, initially effects a small flow diversion, which then becomes greater on account of the limbs 44a, 44b curving into the flow.

The elements shown in Fig. 12a and Fig. 12b can be used in all the arrangements shown above where two structures arranged in a V shape are employed.

In principle, it is possible for all the structures described to be combined with one another in any desired way.